RESEARCH MEMORANDUM

LONGITUDINAL TRIM AND DRAG CHARACTERISTICS OF ROCKET-PROPELLED MODELS REPRESENTING TWO AIRPLANE CONFIGURATIONS

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SUMMARY

An investigation of the longitudinal trim and drag characteristics of two airplane configurations through the transonic speed range is discussed. One configuration employed a thin straight wing and tail and the other incorporated a thicker 35° sweptback wing and a 46° sweptback tail mounted on the same fuselage-fin arrangement.

Both configurations experienced an abrupt longitudinal trim change and a large rapid drag rise in traversing the transonic speed range. The critical Mach numbers for the two configurations were approximately the same.

Longitudinal control by means of the horizontal stabilizer appeared to be feasible throughout the speed range of the tests. Shifts in maneuver-point location were indicated for both configurations in the transonic speed range.

INTRODUCTION

Longitudinal trim and drag characteristics in the transonic speed range are of particular importance to airplane designers. The Langley Pilotless Aircraft Research Division has obtained data of this type for various configurations by means of rocket-propelled models. Data from two configurations were reported in references 1 and 2. In the present investigation two other configurations are covered. One configuration had a 6-percent-thick straight wing and tail while the other had a thicker sweptback wing and tail mounted on the same fuselage-fin arrangement. For each configuration the effect of center-of-gravity location and of stabilizer incidence was investigated.

SYMBOLS

a_n	normal acceleration, feet per second per second
g	gravitational acceleration, 32.2 feet per second per second
i_t	stabilizer incidence relative to fuselage center line, degrees
q	dynamic pressure, pounds per square foot
t	time, seconds
p_T	total pressure, pounds per square foot or pounds per square inch
M	Mach number
S	wing area, square feet
V	velocity, feet per second
W	weight, pounds
γ	angle of tangent to flight path from horizontal, degrees
C_D	drag coefficient $\left(\frac{W}{S}\right)\left(\frac{1}{q}\right)\left(\frac{\Delta V/\Delta t - g \sin \gamma}{g}\right)$
C_N	normal-force coefficient $\left(\frac{W}{S}\right)\left(\frac{1}{q}\right)\left(\frac{a_n}{g}\right)$

MODELS AND APPARATUS

The general arrangement of the models is shown in figures 1 and 2 and the detailed dimensions of both configurations are listed in table I.

The models were constructed mainly of wood. The fuselage was balsa and hardwood with the exception of the nose section which was a detachable metal housing for instruments. The wings and horizontal stabilizer were made of laminated spruce with aluminum plates attached for additional strength and stiffness.

The models were boosted by standard 3.25-inch solid-fuel rocket motors producing 1800 pound-seconds total impulse and sustained by modified 3.25-inch rocket motors producing 1690 pound-seconds total impulse. The models were launched from a zero-length launcher as shown in figure 3.

The instrumentation used to obtain the data was both internal and external to the model. Internal instrumentation consisted of a standard NACA two-channel telemeter, a normal accelerometer, and a total-pressure pickup. The telemetered data were received and calibrated at two separate ground receiving stations. In addition, a CW Doppler radar unit was used to obtain flight-path velocity, a modified SCR-584 tracking radar unit gave range and altitude values, and a standard radiosonde recorded atmospheric data through the altitude range.

TEST AND ANALYSIS PROCEDURE

Tests

The test technique employed consisted of obtaining continuous records of variation of normal force with Mach number for a series of stabilizer incidences and center-of-gravity positions on each of the two configurations. The stabilizer incidences and center-of-gravity positions investigated are listed in the following table:

CONFIGURATION PARAMETERS VARIED

Straight wing		Sweptback wing	
i_t (deg)	c.g. (percent M.A.C.)	i_t (deg)	c.g. (percent M.A.C.)
0.6	0	3.5	0
2.4	0	1.9	0
.4	18	3.6	18
2.2	18	1.9	18
		3.7	25
		2.2	25

All the useful data on the models were obtained during the decelerating part of the flight following sustaining rocket-motor burnout. Figure 4 shows a portion of a typical time-history record of normal acceleration and total pressure.

The Doppler radar unit obtained velocity during the early portion of the flights. Throughout the flights, Mach number and dynamic pressure were obtained from total pressure and free-stream static pressure. Mach number and dynamic pressure were computed from the relationships given in reference 1. The total pressure was obtained from the telemeter record and the free-stream static pressure was obtained from SCR-584 altitude data and radiosonde static pressure against altitude data.

The Reynolds numbers based on the mean aerodynamic chord of the wing ranged from approximately 5×10^6 at $M = 0.80$ to approximately 8×10^6 at $M = 1.20$ for the sweptback-wing configuration. Corresponding values for the straight-wing configuration were about 4.5×10^6 and 7×10^6.

Accuracy

The limits of accuracy are not known precisely; however, in general, the following limits are believed to hold. A telemetered quantity may be in error by 2 percent of the total calibrated instrument range. The full-scale ranges of the models were 40g for the normal acceleration and 35 pounds per square inch for the total pressure, thus the absolute values of these quantities should be correct with 0.80g and 0.70 pounds per square inch, respectively. Experience has shown that the Mach number obtained by the Doppler radar is accurate to the order of 1 percent for nonmaneuvering models. Using this Mach number as a check on the total-pressure Mach number it is believed that the Mach number obtained for the models during decelerating flight is correct within 2 percent in the region near $M = 1.00$. The accuracy is somewhat better at the higher Mach numbers and somewhat less at the lower Mach numbers.

Motion-picture records showed that some of the models rolled during flight and it was felt that the longitudinal data might be affected by the rolling. Analytical investigation by the method of reference 3, however, indicated a negligible effect of the low rolling velocities on the longitudinal characteristics of the models.

Analysis

The normal-force data obtained from a given model were converted to a variation of normal-force coefficient with Mach number to show the trim changes of the configurations. From these data on models with different stabilizer deflections and center-of-gravity positions, a measure of the control effectiveness and maneuvering stability was obtained by the method of reference 1. The variation of the drag coefficient with Mach number was obtained by differentiating the Mach number-time curves.

RESULTS AND DISCUSSION

Longitudinal Trim

The trim normal-force coefficients obtained for different stabilizer incidences and center-of-gravity locations as functions of Mach number are shown in figure 5 for the straight-wing configuration and figure 6 for the sweptback-wing configuration. Both models showed appreciable changes in normal-force coefficient while traversing the transonic speed range. The magnitude of the trim change varied considerably with both center-of-gravity location and stabilizer incidence.

The straight-wing configuration indicated a nose-down pitching tendency at $M = 0.80$, particularly when the model was trimmed for positive lift at subsonic speeds ($i_t = 0.4^{\circ}$ for 18 percent center of gravity, fig. 5(b)). This nose-down tendency was followed by erratic changes in the region between $M = 0.93$ and $M = 0.99$. Near $M = 1.00$, a sharp nose-up pitching occurred and was followed by a leveling off and a gradual nose-down tendency. The sweptback-wing configuration had similar trim changes; however, the nose-up pitching tendency near $M = 1.00$ was not quite so sharp as for the straight wing.

The wind-tunnel configuration of reference 4 was similar to the sweptback configuration and differed only in sweepback of the horizontal stabilizer and relative fuselage-base area. Data from this reference were used to compute the variation of normal-force coefficient with Mach number at a center-of-gravity position of 18 percent mean aerodynamic chord with stabilizer deflections of 1.9° and 3.6° to correspond to conditions for the rocket-model tests. The indicated variations of trim of the wind-tunnel model were quite similar to those of the rocket-propelled models and are shown in figure 6(b). The fact that the rocket-model tests showed the same shape of trim normal-force-coefficient curve as the wind-tunnel tests indicates that the free-flight tests, in spite of the deceleration existing, provided essentially steady trim conditions. An analysis of the transient response for a rocket model of this general type (reference 1) indicated that the trim angle of attack would be maintained within 0.10°.

The changes in normal-force coefficient with Mach number indicated by these tests are functions of both the variations in longitudinal stability and pitching-moment coefficient at zero lift for a given stabilizer setting and center-of-gravity location. From these data alone it is not possible to isolate the two effects. The changes in stability may or may not accentuate the effects of the changes in pitching-moment coefficient. In fact, it may be possible for the two effects to counteract each other; for example, an increase in pitching-moment coefficient combined with an increase in stability could eliminate the sharp change in trim near $M = 1.00$.

Control Effectiveness and Stability

A measure of the stabilizer effectiveness in changing trim lift coefficient of the model $\Delta C_N/\Delta i_t$ was obtained for each center-of-gravity position and is plotted against Mach number in figure 7 for the straight-wing configuration and in figure 8 for the sweptback-wing configuration. Similar results from reference 4 are shown in figure 8(b) for comparison. This parameter is directly proportional to the ability of the horizontal stabilizer to produce a pitching moment and inversely proportional to the longitudinal stability. Thus the variations indicated in $\Delta C_N/\Delta i_t$ with Mach number are the combined effect of stability changes and changes in the effectiveness of the stabilizer to produce moment.

Calculations based on methods derived in reference 5 indicated stabilizer incidences required to overcome curvature of the flight path which were within the limits of experimental accuracy so no attempt was made to isolate this effect.

The location of the maneuver point with respect to the center of gravity is an indication of the degree of longitudinal stability. In the present investigation the locations of the maneuver points were determined by plotting $\Delta i_t/\Delta C_N$ for each center-of-gravity location tested against the center-of-gravity location and by extrapolation determining the center-of-gravity position necessary to make $\Delta i_t/\Delta C_N$ equal zero. The variation of the maneuver point with Mach number determined by this method is given for both configurations in figure 9. Figure 9(b) shows the comparative results of reference 4. Unfortunately, the erratic and abrupt changes in trim made it impossible to determine the maneuver point by this method in the region near $M = 1.00$.

For the sweptback configuration there was a large rearward shift of the maneuver point from 36 percent mean aerodynamic chord at $M = 0.82$ to 96 percent mean aerodynamic chord at $M = 1.14$. As the Mach number increased further there was a slight forward movement. The maneuver point on the straight-wing configuration moved rearward from 34 percent mean aerodynamic chord at $M = 0.80$ to 54 percent mean aerodynamic chord at $M = 0.90$. At $M = 1.05$ the maneuver point had moved forward to 46 percent mean aerodynamic chord and at $M = 1.18$ had returned to the $M = 0.80$ value of 34 percent mean aerodynamic chord. At $M = 1.20$ another rearward shift was indicated. This variation of maneuver-point location for the straight-wing configuration is consistent with the variation noted in reference 6.

In light of the indicated variations of the maneuver points, it would seem that the rather large decreases of stabilizer effectiveness in producing lift $\Delta C_N/\Delta i_t$ are, in the case of the swept configuration, due primarily to an increase in stability. For the straight configuration the stability was approximately the same at $M = 0.80$ and $M = 1.18$ so the decrease in $\Delta C_N/\Delta i_t$ in this range indicates apparent large losses in tail effectiveness in producing pitching moment.

Application to a Full-Scale Airplane

In order to evaluate the trim changes and control effectiveness, the aerodynamic parameters derived from the data have been applied to an assumed full-scale airplane. The assumed conditions for both configurations are a wing loading of 65 pounds per square foot, flight altitude of 35,000 feet, and a center of gravity of 18 percent mean aerodynamic chord.

In order to show the effect of the trim change, the airplane was assumed to have the stabilizer trimmed for level flight at $M = 0.80$ and held fixed at this condition while traversing the transonic region. Figure 10 gives the maximum normal acceleration for the straight configuration which was about 1.2g at $M = 1.05$. The maximum normal acceleration for the sweptback configuration was about 1.9g at $M = 1.2$. These maximum accelerations could be tolerated by both pilot and airplane. In actual flight these accelerations could be reduced by appropriate trimming. The stabilizer incidence for level flight through the transonic region is shown for both configurations in figures 11 and 12. The maximum variation required in stabilizer setting was small for the straight configuration, being of the order of 1°, whereas the sweptback configuration had variations over a 3° range. Both configurations indicate unstable and erratic variations of stabilizer for trim with Mach number in the region between $M = 0.85$ and $M = 1.00$ necessitating rapid control movement to maintain the trim attitude. Trim data from the wind-tunnel tests of reference 4 are also shown on figure 12(b). These data indicate less movement of the stabilizer required for level flight than the rocket model but are in the same direction.

The stabilizer maneuvering effectiveness as given by the parameter $\frac{\Delta a_n/g}{\Delta i_t}$ is given in figure 13 for both configurations.

Drag

The drag coefficient as a function of Mach number is shown in figure 14 for the straight-wing configuration. Similar results are shown for the sweptback configuration in figure 15. These values of drag coefficient correspond to the values of normal-force coefficients given in figures 5 and 6.

For both configurations, a marked drag rise is indicated at $M = 0.90$ rising to a maximum value of approximately 0.080 for the straight configuration and 0.075 for the sweptback configuration at nearly zero lift. The drag rise is slightly more abrupt for the straight configuration. These drag coefficients are of the order of magnitude which might be expected from consideration of the results of previous rocket-model and wind-tunnel tests of similar fuselage-wing combinations. Apparently the sweepback of 35° combined with a more favorable location on the fuselage counteracted the effect of increased thickness used in the sweptback configuration as compared with the straight configuration.

The variation of drag due to lift was found to be in the right direction but, inasmuch as the lift developed was rather low, the actual values of drag increments due to lift were within the experimental accuracy and therefore were not evaluated.

CONCLUSIONS

From the rocket-model flight tests of two airplane configurations, one having a thin straight wing and tail and the other incorporating a thicker sweptback wing and tail, at low lift coefficients the following conclusions may be drawn:

1. Both configurations exhibited erratic and abrupt longitudinal trim changes in the transonic speed range. The trim changes when converted to a full-scale-airplane condition were of sufficiently low magnitude that flight through the transonic speed range could be

accomplished with the stick held fixed for trim level flight at a Mach number of 0.80 without experiencing accelerations greater than 2g.

2. The horizontal stabilizer was found to be an effective device for changing trim lift coefficients of both configurations through the Mach number range tested.

3. Both configurations exhibited shifts in maneuver-point location in the transonic speed range. The maneuver-point location for the straight-wing configuration had returned to the subsonic value at a Mach number of 1.18 while for the sweptback-wing configuration it was 56 percent of the mean aerodynamic chord rearward of the subsonic value at the same Mach number.

4. The two configurations experienced large drag increases in the transonic speed range of similar magnitude.

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3. Phillips, William H.: Effect of Steady Rolling on Longitudinal and Directional Stability. NACA TN 1627, 1948.

4. Osborne, Robert S.: High-Speed Wind-Tunnel Investigation of the Longitudinal Stability and Control Characteristics of a $\frac{1}{16}$-Scale Model of the D-558-2 Research Airplane at High Subsonic Mach Numbers and at a Mach Number of 1.2. NACA RM L9C04, 1949.

5. Phillips, William H.: Appreciation and Prediction of Flying Qualities. NACA Rep. 927, 1949.

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TABLE I

GEOMETRIC CHARACTERISTICS OF TWO CONFIGURATIONS OF AN

AIRPLANE-LIKE TRANSONIC RESEARCH MODEL

Item	Straight wing	Swept wing
Fuselage:		
Over-all length, in. . .	65.52	65.52
Maximum diameter, in. .	7.80	7.80
Fineness ratio	8.40	8.40
Wing:		
Root airfoil section .	NACA 65-006	[a]NACA 63_1-010
Tip airfoil section . .	NACA 65-006	[a]NACA 63_1-012
Angle of incidence, degrees	0	3
Dihedral, degrees . . .	0	-3
Twist, degrees	0	0
Sweepback, degrees . . .	0 of 50 percent chord	35 of 30 percent chord
Aspect ratio	4.00	3.53
Taper ratio	0.50	0.57
Mean aerodynamic chord, in.	10.11	11.30
Total span, in.	39.00	38.84
Area (including fuselage) square feet	2.64	2.97
Tail:		
Airfoil section	NACA 65-006	[a]NACA 63_1-010
Dihedral angle, degrees	0	0
Sweepback, degrees . . .	0 of 50 percent chord	46 of 30 percent chord
Aspect ratio	4.13	3.58
Taper ratio	0.50	0.50
Mean aerodynamic chord, in.	5.06	5.42
Area, square feet . . .	0.68	0.68
Tail height, chords above wing chord plane extended . . .	0.65	0.65
Tail length, chords . .	2.3	2.7

[a]Normal to 30 percent chord.

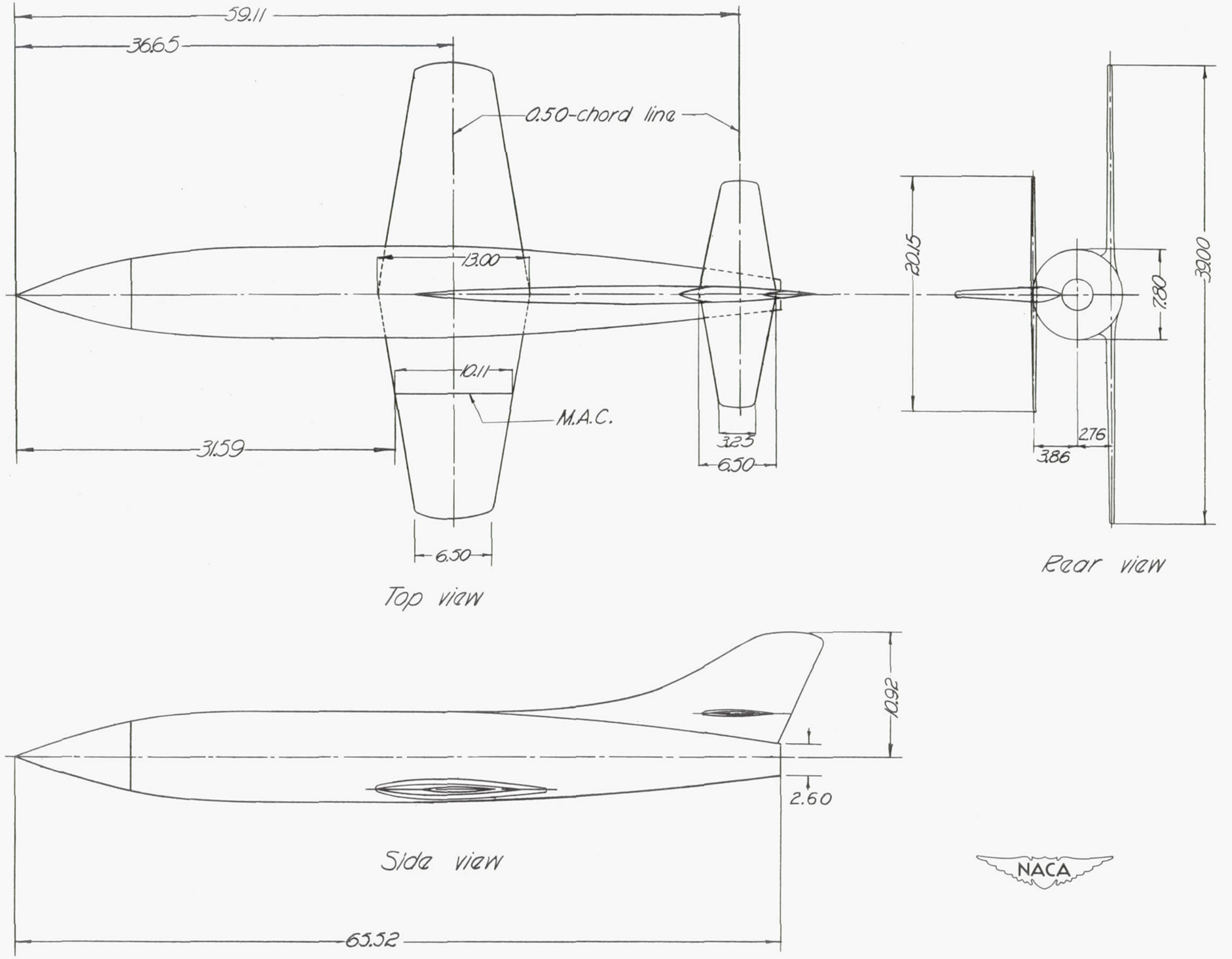


Figure 1.- General arrangement of the straight configuration. All dimensions in inches.

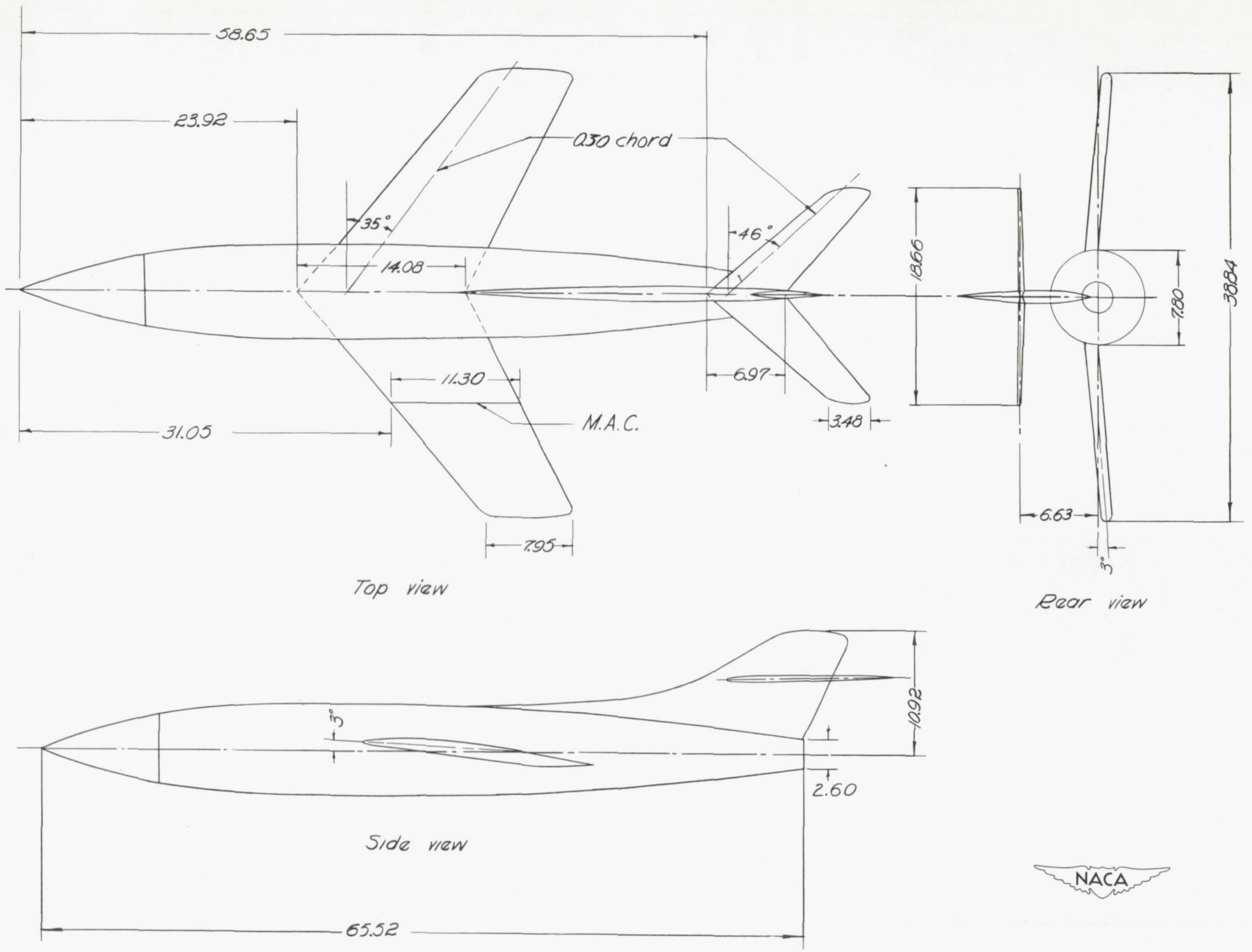
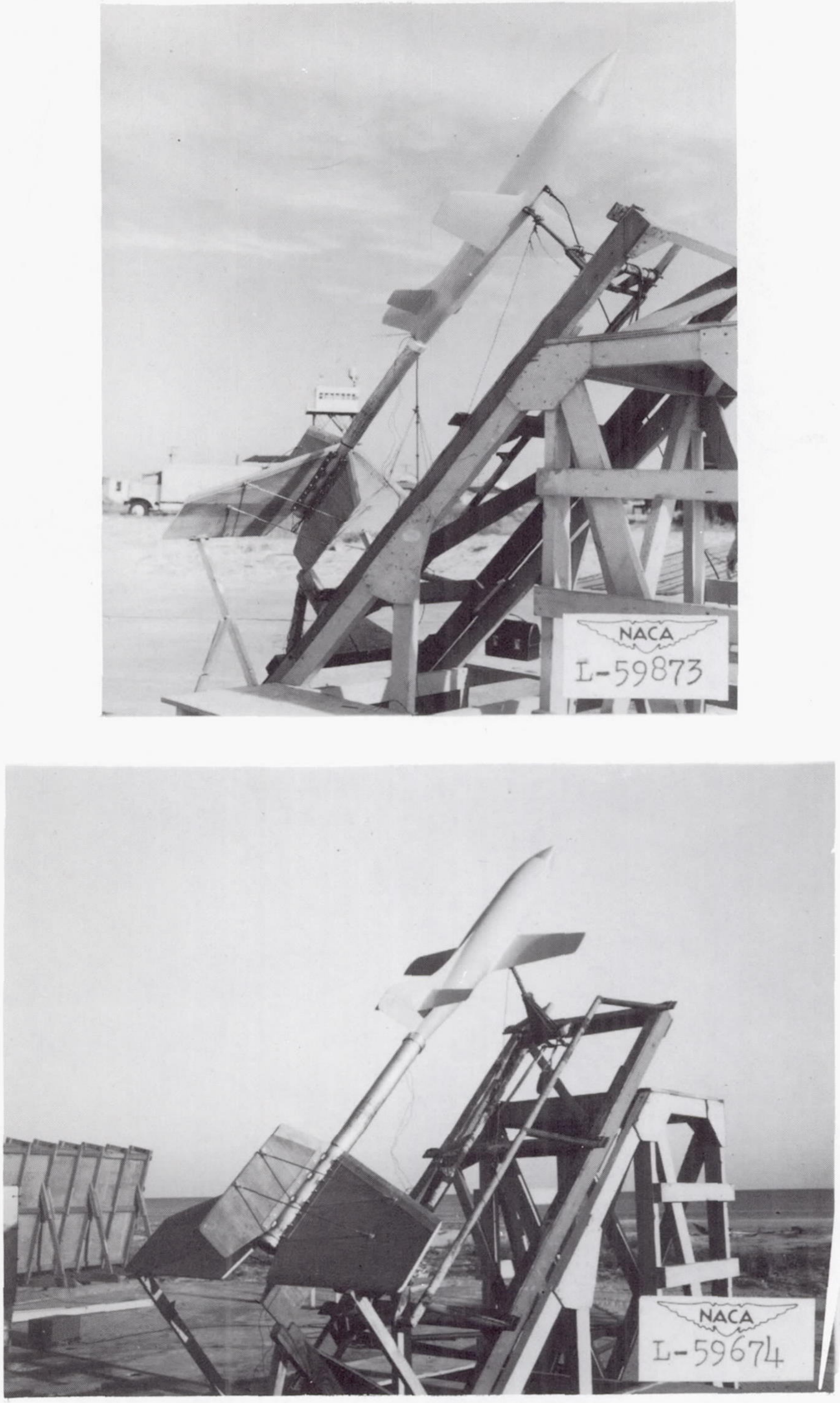
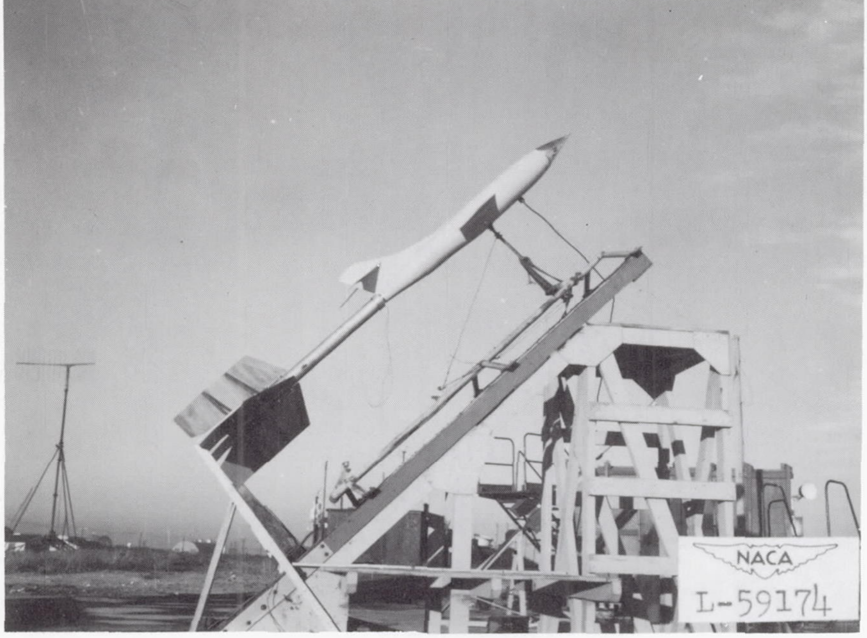


Figure 2.- General arrangement of the swept configuration. All dimensions in inches.



(a) Straight-wing configuration.

Figure 3.- Photographs of models on launcher.



(b) Sweptback-wing configuration.

Figure 3.- Concluded.

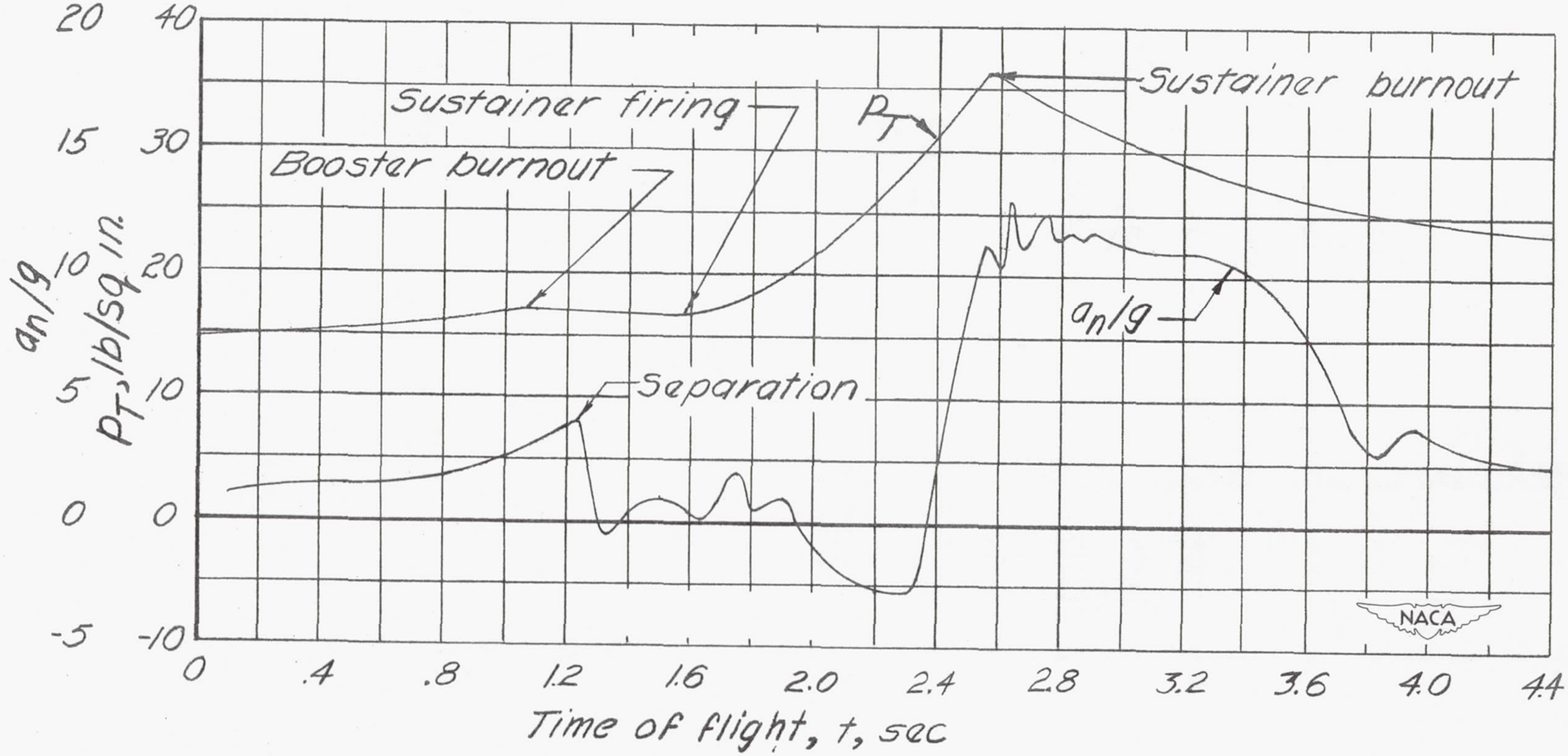


Figure 4.- Typical telemeter time-history record.

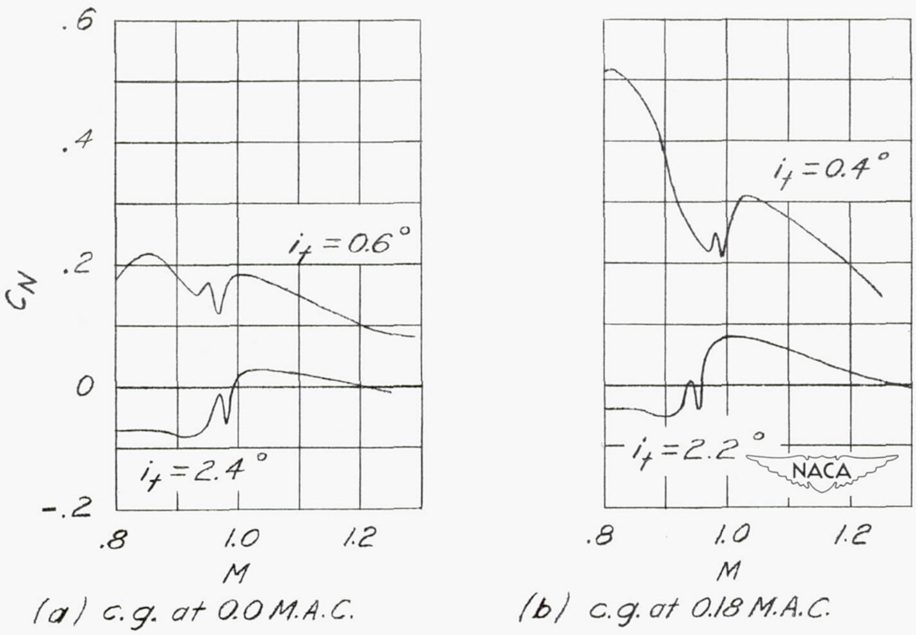


Figure 5.- Variation of trim normal-force coefficient with Mach number for the straight-wing configuration.

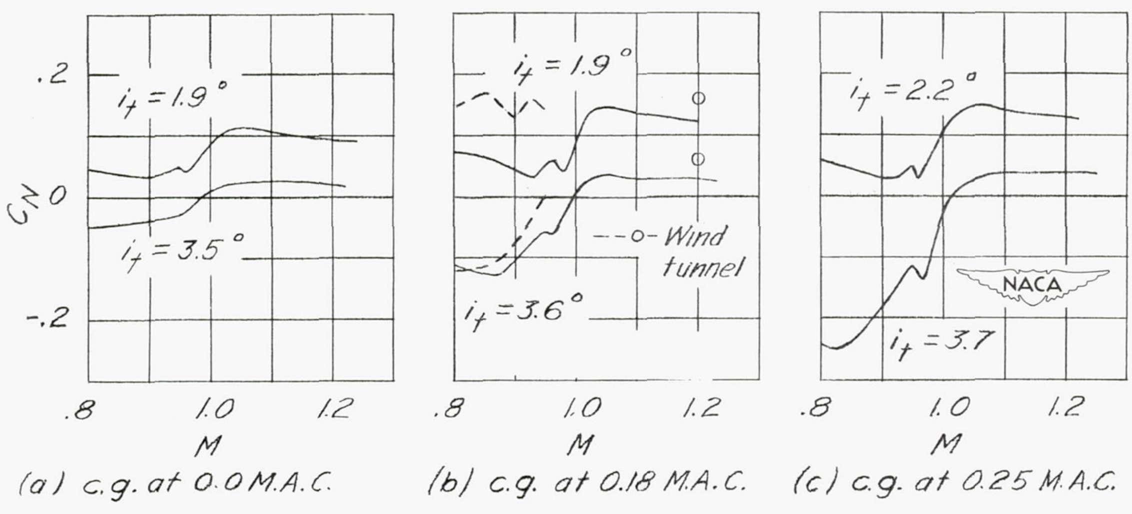


Figure 6.- Variation of trim normal-force coefficient with Mach number for the sweptback-wing configuration.

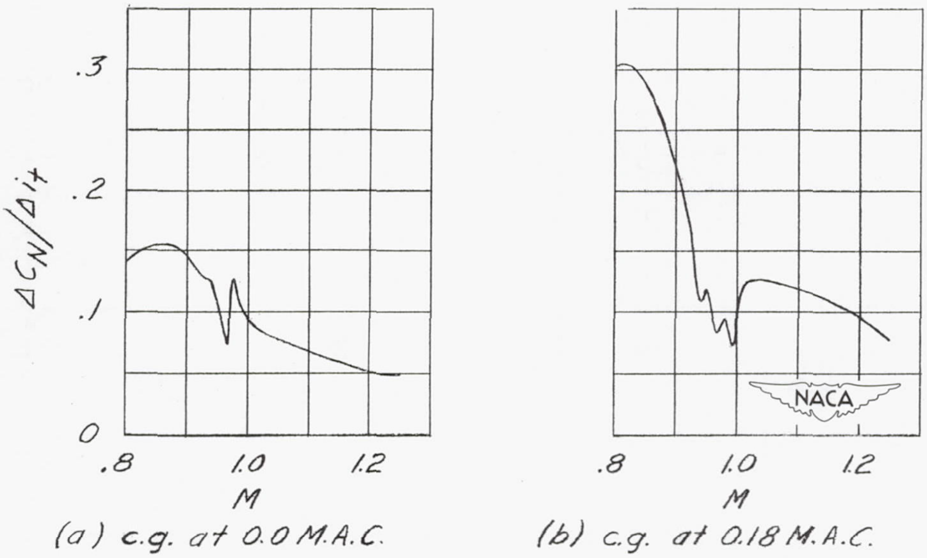


Figure 7.- Variation of the stabilizer-effectiveness parameter $\Delta C_N/\Delta i_t$ with Mach number for the straight-wing configuration.

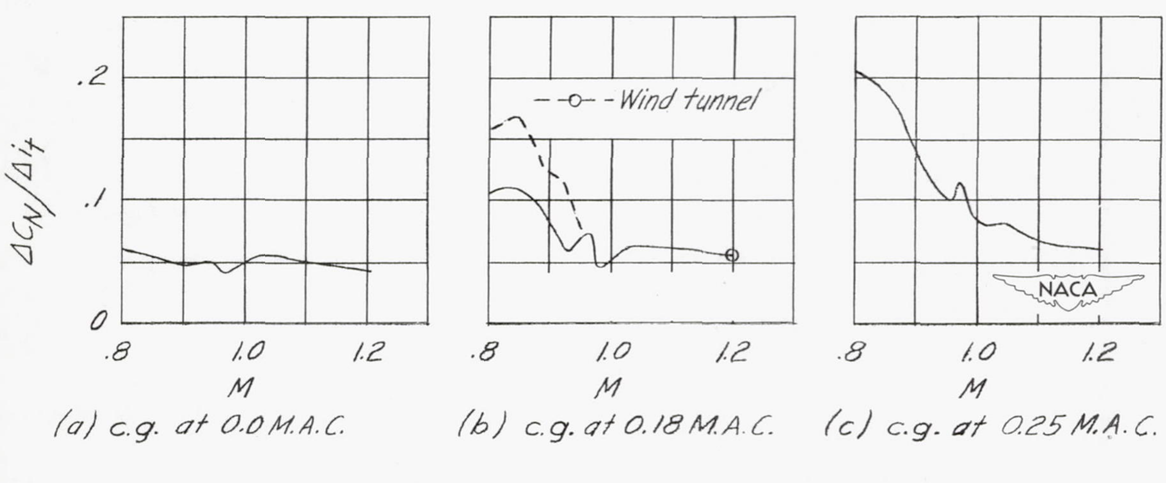


Figure 8.- Variation of the stabilizer-effectiveness parameter $\Delta C_N/\Delta i_t$ with Mach number for the sweptback-wing configuration.

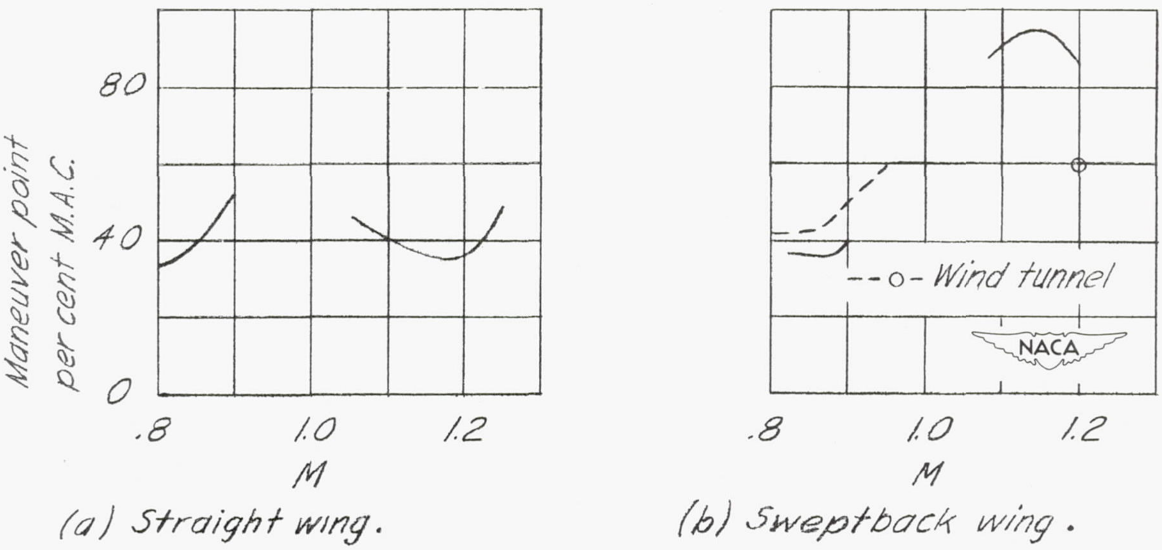


Figure 9.- Variation of the maneuver point with Mach number.

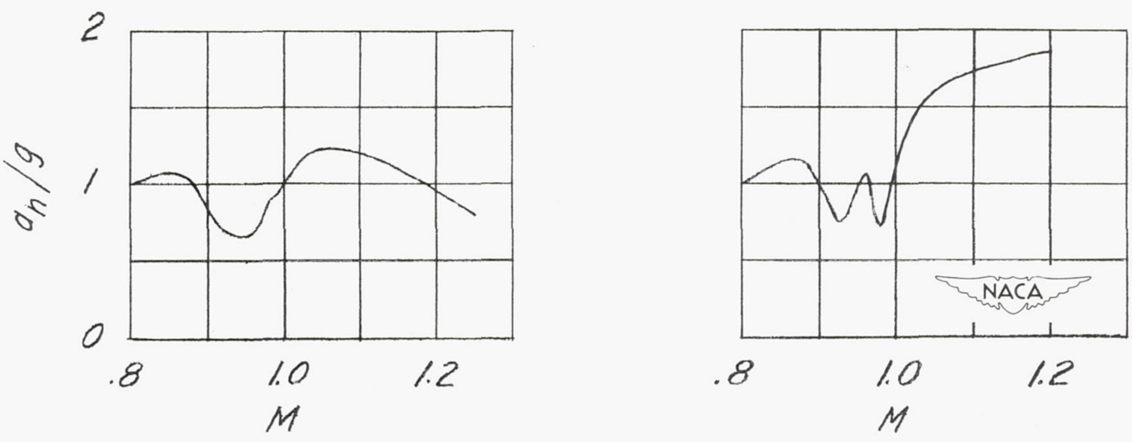


Figure 10.- Variation of normal acceleration with Mach number. Stabilizer set for level flight at $M = 0.8$; $\frac{W}{S} = 65$; altitude, 35,000 feet; center of gravity, 0.18 mean aerodynamic chord.

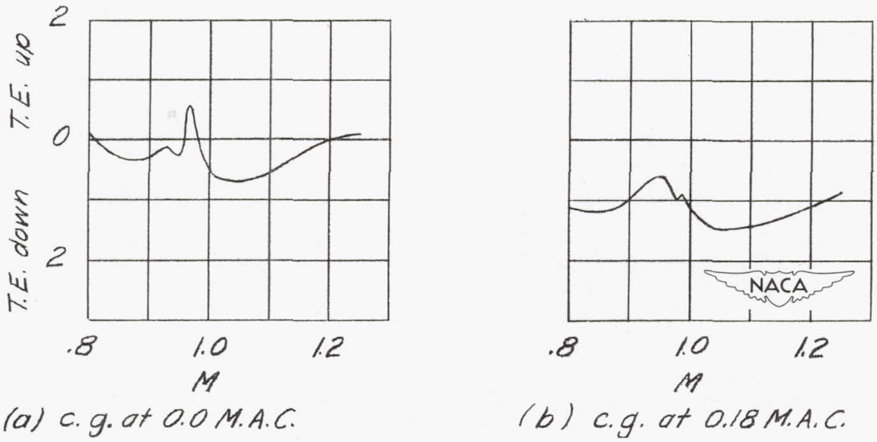


Figure 11.- Variation of the stabilizer incidence required for level flight with Mach number for the straight-wing configuration. $\frac{W}{S} = 65$; altitude, 35,000 feet.

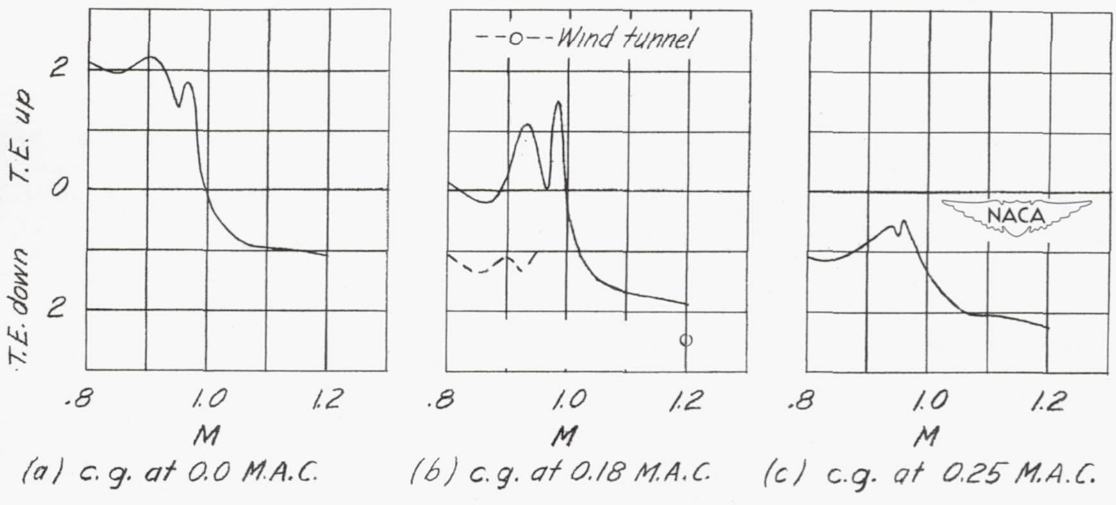


Figure 12.- Variation of the stabilizer incidence required for level flight with Mach number for the sweptback-wing configuration. $\frac{W}{S} = 65$; altitude, 35,000 feet.

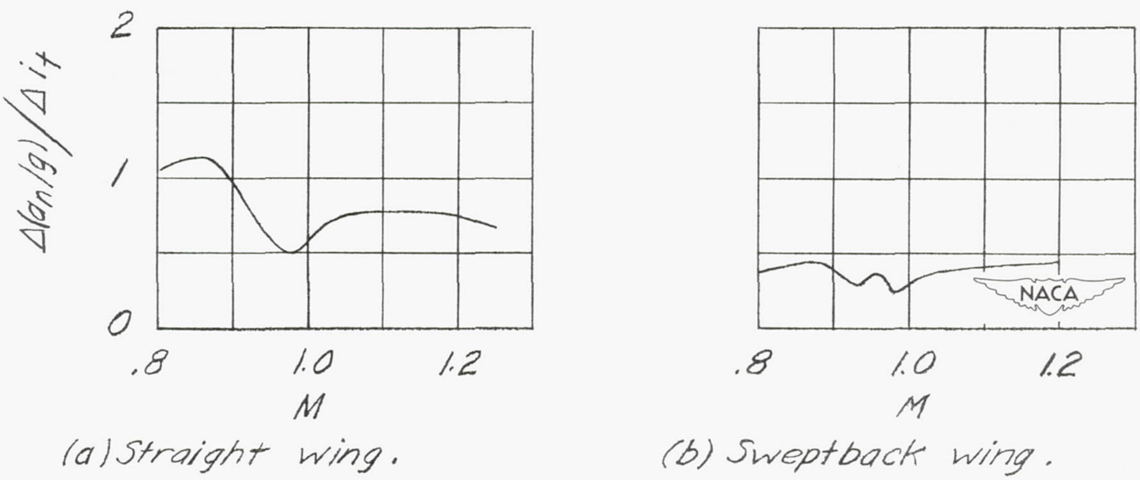


Figure 13.- Variation of the stabilizer maneuvering effectiveness $\Delta(a_n/g)/\Delta i_t$ with Mach number. $\frac{W}{S}$ = 65; altitude, 35,000 feet; center of gravity, 0.18 mean aerodynamic chord.

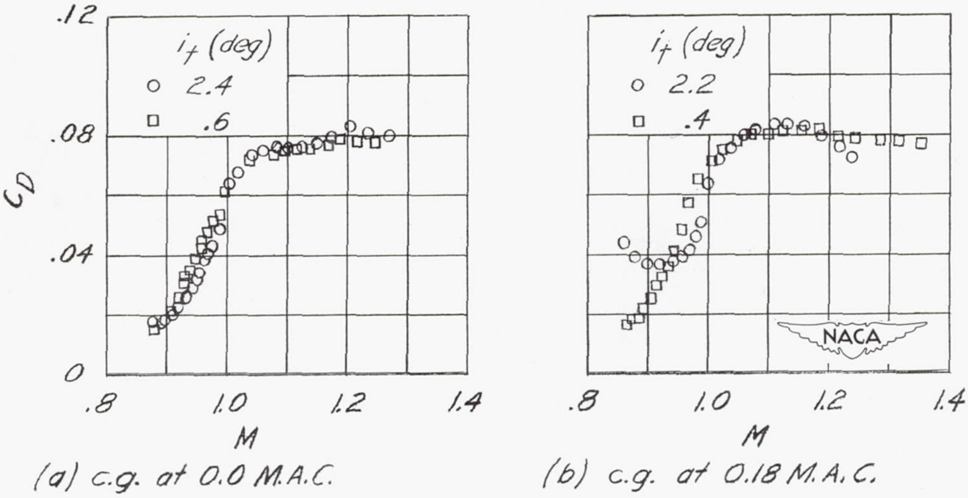


Figure 14.- Variation of the drag coefficient with Mach number for the straight-wing configuration.

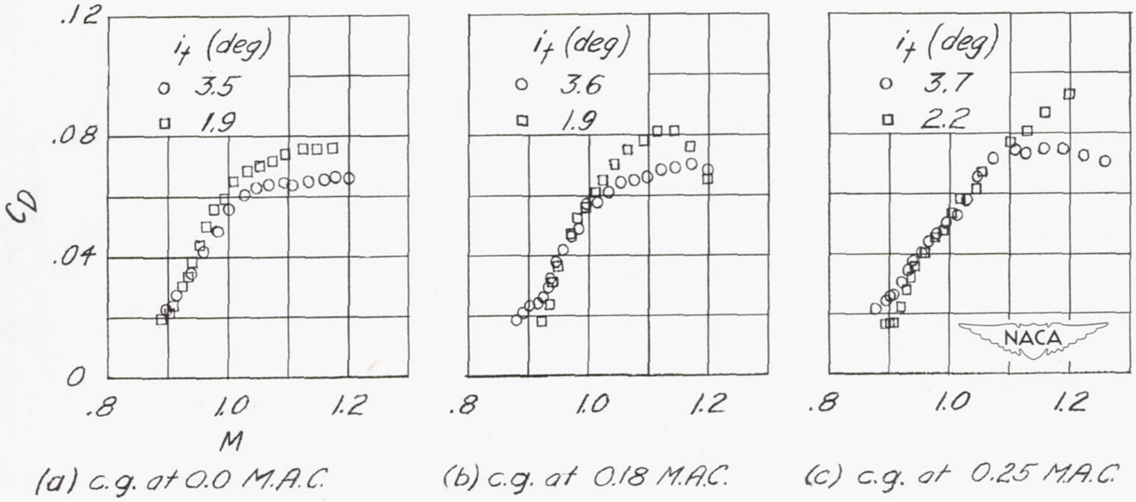


Figure 15.- Variation of the drag coefficient with Mach number for the sweptback-wing configuration.